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ABSTRACT

One of the most remarkable achievements by scientists in the field of global change in recent years is the improved understanding of climate change issues. Its effects on human environments, particularly coastal zones and associated water systems, are now a huge challenge to environmental resource managers and decision makers. International and regional regulatory frameworks have been established to guide the implementation of interdisciplinary methodologies, useful to analyse water-related systems issues and support the definition of management strategies against the effects of climate change. As a response to these concerns, several decision support systems (DSS) have been developed and applied to address climate change through geographical information systems (GIS) and multi-criteria decision analysis (MCDA) techniques; linking the DSS objectives with specific functionalities leading to key outcomes, and aspects of the decision making process involving coastal and waters resources. An analysis of existing DSS focusing on climate change impacts on coastal and related ecosystems was conducted by surveying the open literature. Consequently, twenty DSS were identified and are comparatively discussed according to their specific objectives and functionalities, including a set of criteria (general technical, specific technical and applicability) in order to better inform potential users and concerned stakeholders through the evaluation of a DSS' actual application.

Key words: Climate change, Decision support, GIS, regulations, Environment

1. INTRODUCTION

One of the most remarkable achievements by scientists in the field of global change in recent years is the improved understanding of climate change issues, whose effects have been linked to the increase in global average temperature according to the IPCC emission scenarios [11]. Resulting ocean thermal expansion is expected to generate significant impacts via sea level rise, seawater intrusion into coastal aquifers, enhanced coastal erosion and storm surge flooding, while increasing population in coastal cities, especially megacities on islands and deltas, further aggravates major impacts of climate change on marine coastal regions.

The latter include transitional environments such as estuaries, lagoons, low lying lands and lakes, which are particularly vulnerable because of their geographical location and intensive socio-economic activities [12,13]. Accordingly, several environmental resource regulations have already included the need to assess and manage negative impacts derived from climate change through their implementation. For instance, the European Commission approved the Green and White papers [14-15], the Water Framework Directive (WFD) [16], which represent an integrated and sound approach for the protection and management of water-related resources in both inland and coastal zones.

They also signed the protocol for Integrated Coastal Zone Management (ICZM) [17], useful in the promotion of the integrated management of coastal areas in relation to local, regional, national and international goals. Moreover, the principles of Integrated Water Resources Management (IWRM) aimed to address typical water quality and quantity concerns with the optimisation of water management and sustainability in collaboration with WFD policy declarations [18].

Likewise, relevant national legislations like Shoreline Management Planning (SMP) in the United Kingdom [19], Hazard Emergency Management (HEM) in the United States [20] and Groundwater Resources Management (GRM) in Bangladesh and India [21] were ratified and further endorse the assessment and management of coastal communities in relation to climate change impacts. Decision Support System (DSSs) is computer-based software that can assist decision makers in their decision process, supporting rather than replacing their judgment and, at length, improving effectiveness over efficiency [1].

Environmental DSS are models based tools that cope with environmental issues and support decision makers in the sustainable management of natural resources and in the definition of possible adaptation and mitigation measures [2]. DSS have been developed and used to address complex decision-based problems in varying fields of research. For instance, in environmental resource management, DSS are generally classified into two main categories: Spatial Decision Support Systems (SDSS) and Environmental Decision Supports Systems (EDSS) [3-5]. SDSS provide the necessary platform for decision makers to analyse geographical information in a flexible manner, while EDSS integrate the relevant environmental models, database and assessment tools – coupled within a Graphic User Interface (GUI) – for functionality within a Geographical Information System (GIS) [1-4-6]. In some detail, GIS is a set of computer tools that can capture, manipulate, process and display spatial or geo-referenced data [7] in which the enhancement of spatial data integration, analysis and visualization can be conducted [8-9]. These functionalities make GIS-tools useful for efficient development and effective implementation of DSS within the management process. For this purpose they are used either as data managers (i.e. as a spatial geo-database tool) or as an end in itself (i.e. media to communicate information to decision makers) [8].

At present the increasing trends of industrialisation, urbanisation and population growth has not only resulted in numerous environmental problems but has increased the complexity in terms of uncertainty and multiplicity of scales. Accordingly, there is a consensus on the consideration of several perspectives in order to tackle environmental problems, particularly, climate change related impacts in coastal zones which are characterised by the dynamics and interactions of socio-economic and biogeophysical phenomena. There is the need to develop and apply relevant tools and techniques capable of processing not only the numerical aspects of these problems but also knowledge from experts, to assure stakeholder participation which is essential in the decision making process [5] and to guarantee the overall effectiveness of assessment and management of coastal environments – including related inland watersheds (i.e. surface and groundwater affected by, and affecting, coastal waters).

The scientific community projected that climate change would further exacerbate environmental problems due to natural and anthropogenic impacts – with specific emphasis in coastal areas [10]. This data, nevertheless, depends on global and regional policy measures especially in sectors such as energy, economy and agriculture which seem to be a major threat to global sustainable development. As a response to this, mitigation and adaptation measures are already identified through intense research activities, yet these may not limit the projected effects of climate change over the next few decades On one side there is the influence of socio-economic development and environmental response while on the other there is the significant uncertainty still associated with present climatic predictive models.

Thus, model inputs need to take into account scenarios highly affected by present and future policy measures in order to further reduce uncertainty in their predictions and thereby guarantee robust adaptation strategies. In addition, climate change effects have been linked to the increase in global average temperature according to the IPCC emission scenarios [11]. Resulting ocean thermal expansion is expected to generate significant impacts via sea level rise, seawater intrusion into coastal aquifers, enhanced coastal erosion and storm surge flooding, while increasing population in coastal cities, especially megacities on islands and deltas, further aggravates major impacts of climate change on marine coastal regions. The latter include transitional environments such as estuaries, lagoons, low lying lands, lakes, which are particularly vulnerable because of their geographical location and intensive socio-economic activities [12-13].

Within this context, the development of innovative tools is needed to implement regulatory frameworks and the decision making process required to cope with climate related impacts and risks. To this end, DSS are advocated as one of the principal tools for the described purposes. This work will attempt to examine GIS-based DSS resulting from an open literature survey. It will highlight major features and applicability of each DSS in order to help the reader in the selection of DSS tailored on his specific application needs.

2. DESCRIPTION OF THE EXAMINED DECISION SUPPORT SYSTEMS (DSS)

The literature survey led to identify twenty DSS designed to support the decision making-process related to climate change and environmental issues in coastal environments – including inland watersheds. The identified DSS are listed in Table 1 with the indication of the developer, development years, and literature reference. In order to provide a description of major features and an evaluation of the applicability of the 20 examined DSS, the work adopted the sets of criteria reported in Table 2 and grouped them within three different categories: general technical criteria, specific technical criteria, and availability and applicability criteria.

The general technical criteria underline relevant general features related to each DSS, which include: the target coastal regions and ecosystems domain; the regulatory frameworks and specific legislations supported by each DSS; the considered climate change impacts and related scenarios, as well as the objectives of the examined systems. The specific technical aspects include the main functionalities, analytical methodologies and inference engine (i.e. structural elements) of the systems. A final set of criteria concerned applicability, i.e. scale and study areas, flexibility, status and availability of the examined systems. Within the following sections the identified DSS, listed in Table 1, will be presented discussed according to these criteria

Table 1. List of existing DSS on coastal waters and related inland watersheds.

Name	Developer	Year of Development	Reference Source
CLIME: Climate and Lake Impacts decision support system	Helsinki University of Technology, Finland	1998-2003	[22] http://clime.tkk.fi
CORAL: Coastal Management Decision Support Modelling for Coral Reef Ecosystem	Within a World Bank funded Project :LA3EU	1994-1995	[23]
COSMO: Coastal zone Simulation MOdel	Coastal Zone Management Centre, Hague	1992	[24]
Coastal Simulator decision support system.	Tyndall Centre for Climate Change Research, UK.	2000-2009	[25]
CVAT: Community Vulnerability Assessment Tool	National Oceanic and Atmospheric Administration, US.	1999	[20] www.csc.noaa.gov/products/nchaz/startup.htm
DESYCO: Decision Support SYstem for COastal climate change impact assessment	Euro-Mediterranean Centre for Climate Change, (CMCC) Italy.	2005-2010	[2]
DITTY: Information technology tool for the management of Southern European lagoons	Within the European region project: DITTY	2002- 2005	[26]
DIVA: Dynamic Interactive Vulnerability Assessment	Potsdam Institute for Climate Impact Research, Germany	2003-2004	[27] http://www.dinas-coast.net.
ELBE: Elbe river basin Decision Support System	Research Institute of Knowledge System-RIKS, Netherland	2000-2006	[28] www.riks.nl/projects/Elbe-DSS
GVT:Groundwater Vulnerability Tool	University of Thrace and Water Resource Management Authority, Greece.	2003-2004	[29]
IWRM: Integrated Water Resources Management Decision Support System	Institute of Water Modelling, Bangladesh	2002-2010	[21] www.iwmbd.org
KRIM decision support system	Within the KRIM Project in Germany.	2001-2004	[30] www.krim.uni-bremen.de
MODSIM decision support systems	Labadie of Colorado State University, US	1970	[31-32] www.modsim.engr.colostate.edu
RegIS-Regional Impact Simulator	Cranfield University, UK	2003-2010	[33]http://www.cranfield.ac.uk/sas/naturalresources/research/projects/regis2.html
RAMCO: Rapid Assessment Module Coastal Zone Management	Research Institute of Knowledge System-RIKS, Netherland	1996-1999	[34-35] http://www.riks.nl/projects/RAMCO
SimLUCIA: Simulator model for St LUCIA	Research Institute of Knowledge System-RIKS within the UNEP Project, Netherland	1988-1996	[36] http://www.riks.nl/projects/SimLUCIA

SimCLIM: Simulator model System for Climate Change Impacts and Adaptation	University of Waikato and CLIMsystem limited, New Zealand.	2005	[37] www.climsystems.com
STREAM: Spatial Tools for River Basins and Environment and Analysis of Management Options	Vrije Universiteit Amsterdam and Coastal Zone Management Centre, Hague	1999	[38] http://www.geo.vu.nl/users/ivmstream/
TaiWAP: Taiwan Water Resources Assessment Program to Climate Change	National Taiwan University, Taiwan	2008	[39]
WADBOS: decision support systems	Research Institute of Knowledge System-RIKS, Netherland	1996-2002	[40-41] www.riks.nl/projects/WADBOS

Table 2. List of criteria used for the description of existing DSS.

Categories	Criteria
General technical criteria	• Coping with regulatory framework. This indicates the particular legislation or policy, the DSS refers to and which phase of the decision-making process is supported at the National, Regional and Local level (e.g., EU WFD, ICZM, IWRM, SMP, GRM, and HEM). • Study/ field of application area. The coastal zones where this DSS has been applied and tested (e.g., coastal zone, lakes, river basin, lagoon, groundwater aquifer etc.) • Objective. It specifies the main aims of the DSS. • Climate change impacts. This refers to relevant impacts due to climate change on the system (e.g., sea-level rise, coastal flooding, erosion, water quality). • Climate Change Scenarios. The kind of scenarios considered by the DSS, which are relevant to the system analysis and connected to climate change (e.g., emission, sea level rise, climatic scenarios).
Specific technical criteria	• Functionalities. These indicate relevant functionalities (key outcomes) of the system useful to the decision process: environmental status evaluation, scenarios import (climate change and socio-economic scenarios) and analysis, measure identification and/or evaluation, relevant pressure identification and indicators production. • Methodological tools/ (analytical tools). These indicate the methodologies included in the system such as risks analysis, scenarios construction and/or analysis, integrated vulnerability analysis, Multi-Criteria Decision Analysis (MCDA), socio-economic analysis, uncertainty analysis, ecosystem-based approach etc. • Structural elements. The three major components of the DSS: dataset (i.e., the typology of data), models (e.g., economic, ecological, hydrological and morphological), interface (i.e., addressing if it's user-friendly and desktop or web-based).
Availability and applicability	• Scale and area of application. This specifies the spatiality of the system (e.g., local, regional, national, supra-national and global) within the case study areas. • Flexibility. The characteristics of the system to be flexible, in terms of change of input parameters, additional modules or models and functionalities. It is also linked to the fact that it can be apply on different coastal regions or case study areas. • Status and Availability. This specifies if the system is under development or already developed and ready for use, and if it is restricted to the developer and case study areas only or the public can access it too and the website where information about the DSS can be found.

3 GENERAL TECHNICAL CRITERIA

As far the application domain, the considered DSS focus on coastal zones and related ecosystems (e.g. lagoons, groundwater, river basins, estuaries, and lakes), specifically thirteen DSS are on coastal zones, seven concern coastal associated ecosystems and four focuses on both (Table 3).

As far as regulatory frameworks (i.e. ICZM, WFD, and IWRM) and national legislations are concerned, the examined DSS reflect the assessment and management aspects of the related decision making process. Within the coastal, marine and river basin environments, the assessment phase of these frameworks consists of the analysis of environmental, social, economic and regulatory conditions, while the management phase looks at the definition and implementation of management plans.

Accordingly, support is provided by each DSS to the implementation of one or two frameworks in the assessment and/or management phase in relation to specific objectives and application domain. Specifically, the investigated DSS can provide the evaluation of ecosystem pressures, the assessment of climate change hazard, vulnerability and risks, the development and analysis of relevant policies, and the definition and evaluation of different management options. Eight out of the twenty examined DSS provide support for the ICZM implementation through an integrated assessment involving regional climatic, ecological and socio-economic aspects (Table 3, second column).

With respect to the WFD (i.e. six DSS) and IWRM (i.e. seven DSS), the main focus is on the assessment of environmental or ecological status of coastal regions and related ecosystems and on the consideration of anthropogenic impacts and risks on coastal resources. These two groups of DSS consider also the river basins management via evaluation of adaptation options, which is essential for the management phase of the WFD and IWRM implementation. Particularly interesting are the approaches adopted by three DSS: CLIME, STREAM and COSMO. CLIME supports both the assessment and management phases of WFD through the analysis of present and future climate change impacts on ecosystems and the socio-economic influence on water quality of the European lakes.

STREAM evaluates climate change and land use effects on the hydrology of a specific river basin, in order to support the management phase of IWRM and WFD via the identification of water resources management measures. Lastly, COSMO provides support for the ICZM through the identification and evaluation of feasible management strategies for climate change and anthropogenic impacts relevant for coastal areas. Moreover, RegIS, Coastal Simulator, CVAT and GVT specifically support the implementation of national legislations through the consideration of socio-economic and technological issues relevant for identifying suitable mitigation actions. To this purpose, these DSS promote the involvement of stakeholders through participatory processes.

The main objective of the examined DSS is the analysis of vulnerability, impacts and risks, and the identification and evaluation of related management options, in order to guarantee robust decisions required for sustainable management of coastal and inland water resources. Specifically, the objectives of the examined DSS are concerned with three major issues: (1) the assessment of vulnerability to natural hazards and climate change (four DSS: CVAT, GVT, SimLUCIA, TaiWAP); (2) the evaluation of present and potential climate change impacts and risks on coastal zones and linked ecosystems, in order to predict how coastal regions will respond to climate change (nine DSS); (3) the evaluation or analysis of management options for the optimal utilisation of coastal resources and ecosystems through the identification of feasible measures and adequate coordination of all relevant users/stakeholders (seven DSS: WADBOS, COSMO CORAL, DITTY, ELBE, MODSIM, RAMCO).

Table 3. List of the examined DSSs according to the general technical criteria (ND: Not Defined).

Name	Application domain	Regulatory Framework of reference	Objective	Climate change impacts addressed	Climate change scenarios generating impacts
CLIME	• Lakes.	WFD for environmental assessment.	To explore the potential impacts of climate change on European lakes dynamics linked coast.	• Water quality.	• Emission scenarios. • Temperature scenarios.
CORAL	• Coral reef	IWRM and ICZM both for environmental assessment and management.	Sustainable management of coastal ecosystems in particular, coral reef.	• ND	• ND
COSMO	• Coastal zones.	ICZM for environmental management.	To evaluate coastal management options considering anthropic (human) forcing and climate change impacts.	• Sea-level rise.	• Sea-level rise scenarios.
Coastal Simulator	• Coastal zones.	National legislation for environmental assessment and management.	Effects of climate change /management decisions on the future dynamics of the coast.	• Storm surge flooding. • Coastal erosion.	• Emission scenarios. • Sea-level rise scenarios.
CVAT	• Coastal zones.	National legislation for environmental assessment and management.	To assess hazards, vulnerability and risks related to climate change and support hazard mitigation options.	• Storm surge flooding. • Coastal erosion. • Cyclone. • Typhoon. • Extreme events	• Past observations
DESYCO	• Coastal zones. • Coastal Lagoons	ICZM for environmental assessment and management.	To assess risks and impacts related to climate change and support the definition of adaptation measures.	• Sea-level rise. • Relative sea-level rise • Storm surge flooding. • Coastal erosion. • Water quality	• Emission scenarios. • Sea level rise scenarios.
DITTY	• Coastal Lagoons.	IWRM and WFD for environmental management.	To achieve sustainable and rational utilization of resources in the southern European lagoons by taking into account major anthropogenic impacts.	• ND	• ND
DIVA	• Coastal zones.	ICZM for environmental assessment and management.	To explore the effects of climate change impacts on coastal regions.	• Sea-level rise. • Coastal erosion. • Storm surge flooding.	• Emission scenarios. • Sea-level rise scenarios.
ELBE	• River basin. • Catchment.	WFD for environmental management.	To improve the general status of the river basin usage and provide sustainable protection measure within coast.	• Precipitation and temperature variation.	• Emission scenarios.
GVT	• Coastal zones.	National legislation for environmental assessment.	To describe the vulnerability of groundwater resources to pollution in a particular coastal region.	• Groundwater quality. • Saltwater intrusion.	• Sea-level rise scenarios.

IWRM	• Coastal zones. • River basin	IWRM for environmental assessment and management.	To explore potential risks on coastal resources due to climate and water management policies.	• Sea-level rise. • Coastal erosion.	• Sea-level rise scenarios. • Emission scenarios.
KRIM	• Coastal zones.	ICZM for environmental assessment.	To determine how coastal systems reacts to climate change in order to develop modern coastal management strategies.	• Sea-level rise. • Extreme events. • Coastal erosion.	• Sea-level rise scenarios. • Extreme events scenarios.
MODSIM	• River basin.	IWRM for environmental management.	To improve coordination and management of water resources in a typical river basin.	• ND	• ND
RegIS	• Coastal zones.	SMP and Habitats regulation (UK) for environmental assessment and management.	To evaluate the impacts of climate change, and adaptation options.	• Coastal and river flooding. • Sea level rise	• Emission scenarios • Socio-economic scenarios • Sea level rise scenarios
RAMCO	• River basin. • Coastal zones.	WFD and ICZM for environmental assessment and management.	For effective and sustainable management of coastal resources at the regional and local scales.	• ND	• ND
SimLUCIA	• Coastal zones.	National legislation for environmental assessment.	To assess the vulnerability of low lying areas in the coastal zones and island to sea-level rise due to climate change.	• Sea-level rise. • Coastal erosion. • Storm surge flooding.	• Sea-level rise scenarios.
SimCLIM	• Coastal zones.	ICZM for environmental assessment and management.	To explore present and potential risks related to climate change and natural hazards (e.g. erosion, flood).	• Sea-level rise. • Coastal flooding. • Coastal erosion.	• Sea-level rise scenarios.
STREAM	• River basin. • Estuaries.	IWRM and WFD for environmental management.	To integrate the impacts of climate change and land-use on water resources management.	• Water quality variation. • Salt intrusion.	• Emission scenarios.
TaiWAP	• River basin.	IWRM for environmental assessment.	To assess vulnerability of water supply systems to impacts of climate change and water demand.	• Water quality variations.	• Emission scenarios.
WADBOS	• River basin. • Coastal zones.	WFD and ICZM for environmental assessment and management.	To support the design and analysis of policy measures in order to achieve an integrated and sustainable management.	• ND	• ND

According to the climate change impacts considered by the examined DSS, the review highlights that fifteen out of the 20 DSS applications regard the assessment of climate change impacts and related risks (CC-DSS). These DSS consider climate change impacts relative to sea level rise, coastal erosion, and storm surge flooding and water quality. In particular, DESYCO also consider relative sea level rise in coastal regions where there are records of land subsidence, whereas KRIM and CVAT assess impacts related to extreme events and natural hazards (e.g. typhoon, cyclone, etc.) respectively. Moreover, GVT is specifically devoted to groundwater quality variations.

The relevant climate change related scenarios considered by the examined DSS refer to emission of greenhouse gases, temperature increase, sea level rise and occurrence of extreme events. In addition, CVAT used previous observations as baseline scenarios for the assessment of natural hazards; while RegIS considered scenarios related to coastal and river flooding along with socio-economic scenarios in order to estimate their potential feedback on climate change impacts. Although most of these CC-DSS applications used sea level rise scenarios, only DIVA used global sea level rise scenarios to estimate related impacts like coastal erosion and storm surge flooding. KRIM is the only DSS considering extreme events scenarios in its analysis to support the development of robust coastal management strategies.

4. SPECIFIC TECHNICAL CRITERIA

The criteria related to the specific technical aspects are reported in Table 4. As far as the functionalities are concerned (Table 4, first column), the ones implemented by DESYCO, COSMO, SimCLIM, KRIM and RegIS include the identification and prioritisation of impacts, targets and areas at risk from climate change, sectorial evaluation of impacts or integrated assessment approach, and vulnerability evaluation and problem characterisation. These are to effectively differentiate and quantify impacts and risks at the regional scale. Moreover, they also support the definition and evaluation of management options through GIS-based spatial analysis. Other DSS, i.e. DIVA, SimCLIM and KRIM, implement scenarios import and generation, environmental status evaluation, impacts and vulnerability analysis and evaluation of adaptation strategies to adequately achieve a sustainable state of coastal resources and ecosystems.

Table 4. List of the examined DSSs according to the specific technical criteria.

Name	Functionalities	Analytical methodologies	Structural elements
CLIME	• Identification of pressure generated by climatic variables. • Environmental status evaluation. • Water quality evaluation related to climate change. • Socio-economic evaluation. • Spatial analysis (GIS).	• Scenarios construction and analysis. • Probabilistic Bayesian network. • Uncertainty analysis.	• Climatic, hydrological, chemical, geomorphological data. • Climate, ecological and hydrological models. • Web-based user interface
CORAL	• Evaluation of management strategies • Spatial analysis (GIS).	• Scenarios construction and analysis. • Cost-effectiveness analysis. • Ecosystem-based.	• Environmental, socioeconomic, ecological, biological data. • Economic and ecological models. • Desktop user interface.
COSMO	• Problem characterization (e.g. water quality variation, coastal erosion etc.) • Impact evaluation of different development and protection plans. • Indicator production. • Spatial analysis (GIS).	• Scenarios construction and analysis. • MCDA. • Ecosystem-based	• Socio-economic, climatic, environmental, hydrological data. • Ecological, economic and hydrological models. • Desktop user friendly interface
Coastal Simulator	• Environmental status evaluation. • Management strategies identification and evaluation. • Indicator production. • Spatial analysis (GIS).	• Scenarios construction and analysis. • Uncertainty analysis. • Risk analysis. • Ecosystem-based.	• Climatic, socio-economic, environmental, hydrological, geomorphological data. • Ecological, morphological climatic and hydrological models. • Desktop user interface.
CVAT	• Environmental status evaluation. • Hazard identification. • Indicators production. • Mitigation options identification and evaluation. • Spatial analysis (GIS).	• Hazard analysis. • Critical facilities analysis. • Society analysis. • Economic analysis. • Environmental analysis. • Mitigation options analysis.	• Environmental and socio-economic data. • Hydrological model. • Desktop user friendly interface

DESYCO	• Prioritization of impacts, targets and areas at risk from climate change. • Impacts, vulnerability and risks identification. • Indicators production. • Adaptation options definition • Spatial analysis (GIS).	• Regional Risk Assessment methodology. • Scenarios construction and analysis. • MCDA. • Risk analysis.	• Climatic, biophysical, socio-economic, geomorphological, hydrological data. • Desktop automated user interface.
DITTY	• Management options evaluation • Indicator production. • Spatial analysis (GIS).	• Scenarios construction and analysis. • Uncertainty analysis. • MCDA. • Social cost and benefits analysis. • DPSIR.	• Morphological, social, hydrological, ecological data. • Hydrodynamics, biogeochemical, socio-economic models. • Desktop user interface.
DIVA	• Scenarios generation and analysis. • Environmental status evaluation. • Indicators production. • Adaptation options evaluation. • Spatial analysis (GIS).	• Scenarios construction and analysis. • Cost-benefit analysis. • Ecosystem-based.	• Climatic, socio-economic, geography, morphological data. • Economic, ecological, geomorphological, climate models. • Desktop graphical user interface.
ELBE	• Environmental status evaluation. • Protection measures identification. • End-user involvement. • Spatial analysis (GIS).	• Scenarios construction and analysis.	• Hydrological, ecological, socio-economic, morphological data. • Economic, • Hydrological, models. • Desktop complex user interface.
GVT	• Environmental status evaluation. • Indicators production • Spatial analysis (GIS). • Impact and vulnerability evaluation	• Risks analysis. • Fuzzy logic. • MCDA.	• Data (environmental, climatic, hydrological, socioeconomic). Hydrological, socioeconomic and DEM models. • Desktop user interface.
IWRM	• Environmental status evaluation. • Indicators production. • Adaptation measures evaluation. • Information for non-technical users. • Spatial analysis (GIS).	• Scenarios construction and analysis. • Risk analysis. • Cost-benefit analysis. • Socio-economic analysis.	• Climatic, environmental, socio-economic, geomorphological data. • Hydrodynamic, climate, economic models. • Desktop user interface.
KRIM	• Environmental status evaluation. • Adaptation measures evaluation. • Information for non-technical users. • Spatial analysis (GIS).	• Scenarios construction and analysis. • Impact and risk analysis. • Ecosystem-based.	• Climatic, socio-economic, ecological, environmental, hydrological data. • Economic, ecological, hydrodynamic, geomorphological models. • Desktop user interface.

MODSIM	• Environmental status evaluation. • Management measures evaluation. • Spatial analysis (GIS).	• Statistical analysis. • Analysis of policies.	• Administrative, hydrological, socio-economic, environmental data. • Socio-economic, hydrological models. • Web-based user interface.
RegIS	• Indicators production • Management measures evaluation. • Information for non-technical users. • sectoral evaluation • Spatial analysis (GIS).	• Scenarios construction and analysis. • Impact analysis. • DPSIR. • Integrated assessment.	• Climatic, socio-economic, geomorphological, hydrological data. • Climate and flood metal-models. • Desktop user interface.
RAMCO	• Environmental status evaluation. • Indicators generation. • Management measures evaluation. • Spatial analysis (GIS).	• Scenarios construction and analysis. • Cellular automata. • Ecosystem-based.	• Socio-economic, environmental, climatic data. • Biophysical, socio-economic and environmental models. • Web-based user interface.
SimLUCIA	• Indicators production. • Impact and vulnerability evaluation. • Management and land-use measures evaluation. • Spatial analysis (GIS).	• Cellular Automata. • Scenarios construction and analysis. • Socio-economic analysis. • Bayesian probabilistic networks. • Ecosystem-based.	• Climatic, environmental, socio-economic data. • Land use, social and economic, climate models. • Web-based user interface.
SimCLIM	• Environmental status evaluation. • Impact and vulnerability evaluation. • Adaptation strategies evaluation • Spatial analysis (GIS).	• Scenario construction and analysis. • Statistical analysis. • Risk analysis. • Cost/benefit analysis. • Ecosystem-based.	• Climatic, hydrological, socio-economic data. • Climate, hydrological, economic models. • Desktop user interface.
STREAM	• Environmental status evaluation. • Indicators production. • Management measures evaluation spatial analysis (GIS).	• Scenarios construction and analysis.	• Climatic, socio-economic, ecological, hydrological data. • Climate, hydrological models. • Web-based user interface.
TaiWAP	• Environmental status evaluation.- • Indicators production. • Spatial analysis (GIS).	• Scenarios construction and analysis. • Impact and vulnerability analysis.	• Climatic, socio-economic, hydrological data. • Climate, hydrological, water system dynamic models. • Desktop user interface.
WADBOS	• Management measures identification and evaluation. • Spatial analysis (GIS).	• Scenarios construction and analysis. • Sensitivity analysis. • MCDA.	• Socio-economic, hydrological, environmental, ecological data. • Socio-economic, ecological, landscape models. • Desktop user interface.

In order to effectively support the assessment and management of groundwater resources, GVT and DESYCO estimate indicators in assessing impacts, vulnerability and risks to estimate groundwater quality and coastal environmental quality, respectively. Similarly, STREAM, ELBE, RAMCO and DITTY employ environmental status evaluation, protection measures identification, and spatial analysis to support the management aspects of coastal ecosystems. Moreover, CLIME and CORAL specifically support the assessment and management of lakes and coral reefs via the adoption of management strategies and the evaluation and identification of pressures from climatic variables.

In particular, five out of the 20 examined DSS (i.e. CVAT, GVT, Coastal Simulator, SimLUCIA and RegIS) consider hazards identification, impacts and vulnerability evaluation, mitigation/ management options identification and evaluation and sectoral evaluation to achieve a comprehensive and integrated analysis of coastal issues at the local or regional scale. Among all considered DSS, RegIS is the one most oriented to stakeholders.

The second column of table 4 shows the methodologies adopted by each DSS. Seventeen out of 20 examined DSS consider scenarios analysis to enable coastal managers, decision makers and stakeholders to anticipate and visualise coastal problems in the foreseeable future, and to better understand which future scenario is most suitable for consideration in the evaluation process. A useful methodology is represented by the Multi-Criteria Decision Analysis (MCDA) technique that is considered by five DSS (i.e. COSMO, DESYCO, DITTY, GVT and WADBOS) in order to compare, select and rank multiple alternatives that involve several attributes based on several different criteria.

Moreover, DITTY and RegIS also consider the DPSIR approach as a causal framework to describe the interactions between the coastal system, society and ecosystems to carry out an integrated assessment with the aim to protect the coastal environment, guarantee its sustainable use, and conserve its biodiversity in accordance to the Convention on Biodiversity (2003). An ecosystemic assessment was developed nine DSS (i.e. CORAL, COSMO, Coastal simulator, DIVA, RegIS, KRIM, RAMCO, SimLUCIA, SimCLIM) to support the analysis of the studied region through the representation of relevant processes and their feedbacks.

Furthermore KRIM, IWRM, COSMO, SimCLIM and Coastal Simulator employ the risk analysis approach for impacts and vulnerability evaluation and also for general environmental status evaluation. A more detailed approach to risk analysis, through the regional risk assessment methodology (RRA), was adopted by DESYCO, Coastal Simulator and RegIS with huge emphasis on the local or regional scales. Finally, CLIME and SimLUCIA consider the Bayesian probability network to highlight the causal relationship between ecosystems (e.g. lakes) and climate change effects.

With regard to the structure of examined DSS (Table 4, third column), most of them employ analytical models useful to highlight the basic features and natural processes of the examined territory, such as the landscape and ecological models used by the WADBOS, the environmental model employed by RAMCO, the geomorphological model used within KRIM and the flood meta-model which interface other models considered by the RegIS. Moreover, the majority of these DSS utilise numerical models necessary to simulate relevant circulation and geomorphological processes that may influence climate change and related risks. DSS like CLIME, DESYCO, CVAT and TaiWAP adopt models useful to represent specific climatic processes (e.g. hydrological cycle and fate of sediment). More importantly, ten (i.e. WADBOS, SimLUCIA, RAMCO, MODSIM, GVT, ELBE, DIVA, CORAL, DITTY AND SimCLIM) out of the twenty examined DSS consider relevant socioeconomic models outputs in their analysis to critically support the integrated assessment of coastal zones.

Finally, the majority of these DSS consider integrated assessment models in order to emphasise the basic relationship among different categories of environmental processes such as physical, morphological, chemical, ecological and socio-economic – and to provide inclusive information about the environmental and socioeconomic processes. As far as the software interfaces are concerned, very few of the examined DSS are applied through web-based interfaces, in spite of the fact that web-based facilities enhance easy access to information within a large network of users. Furthermore, all the reviewed DSS consider GIS tools as basic media to express their results or outputs in order to provide fast and intuitive results representation to non-experts (i.e. decision makers and stakeholders) and empower them for robust decisions. In addition to maps, the outputs produced by each DSS are also graphs, charts, and statistical tables.

5. APPLICABILITY CRITERIA

Table 5 shows the implementation of the criteria concerning applicability to the examined DSS. Applicability includes three aspects: scale/study areas, flexibility and status/availability (Table 2). The spatial scales considered were five: global, supranational, national, regional, and local, in order of decreasing size. The study areas are those reported in the literature cited in Table 1. The flexibility derives from the capability of a given DSS to include new modules and models in its structure, thus new input parameters, and the suitability to be used for regionally different case studies. In order to visualize the estimation of the overall flexibility of a system, highly flexible/flexible/moderately-to-no flexible were indicated as +++/++/+. Status and availability refer to different extent of development (e.g. research prototype, commercial software) and public accessibility/last updated version, respectively.

Table 5. List of the examined DSSs according to the applicability criteria
(+++, highly flexible; ++, flexible; +: moderately to no-flexible).

Name	Scale and area of application	Flexibility	Status and availability last updated version (year)
CLIME	•Supra-National, National, Local. (Northern, western and central part of Europe).	+++ Flexible in structural modification and study area.	Available to the public. Demo. 2010.
CORAL	•Regional, Local. (Coastal areas of Curacao; Jamaica and Maldives).	+++ Flexible in study area.	Not available to the public. Prototype. 1995.
COSMO	•National, Local. (Coast of Netherland).	++ Flexible in study area.	Commercial application. 1998.
Coastal Simulator	•National, Regional, Local. (Coast of Norfolk in East Anglia, UK).	+	Available only to the Tyndall Research Centre. Prototype. 2009
CVAT	•Regional, Local. (New Hanover County, North Carolina).	++ Flexible in study area.	Available to public. Prototype. 2002.
DESYCO	•Regional, Local. (North Adriatic Sea).	++ Flexible in study area.	Not available to the public. Prototype. 2010.
DITTY	•Supranational, National, Regional. (Ria Formosa-Portugal; Mar Menor-Spain; Etang de Thau-France; Sacca di Goro-Italy, Gera-Greece).	+++ Flexible in study area.	Not available to the public. 2006
DIVA	•Global, National.	+++ Flexible in study area.	Available to the public. 2009
ELBE	•Local. (Elbe river basin Germany).	+	Available to the public. 2003
GVT	•Regional, Local. (Eastern Macedonia and Northern Greece).	+	Not available to the public. 2006
IWRM	•Regional, Local. (Halti-Beel, Bangladesh)	++ Flexible in study area.	Not available to the public. Prototype. 2009

KRIM	• Regional. (German North sea Coast, Jade-Weser area in Germany).	+	Not available to the public. Prototype. 2003
MODSIM	• National, Regional. (San Diego Water County, Geum river basin- Korea).	++ Flexible in study area.	Available to the public online. 2006
RegIS	•Regional, Local. (North-West, East Anglia).	++ Flexible in study area.	Available online to stakeholders. Prototype. 2008
RAMCO	•Regional, Local. (South-West Sulawesi coastal zone).	++ Flexible in the used dataset and concepts.	Not available to the public. Prototype. 1999
SimLUCIA	•Local (St Lucia Island, West India)	+	Available online to the public. Demo. 1996
SimCLIM	•National, Regional, Local. (Rarotonga Island, Southeast Queensland).	++ Flexible in structural modification and study area.	Available to the public. Demo. 2009
STREAM	•Regional, Local. (Ganges/Brahmaputra river basin, Rhine river basin, Yangtze river basin and Amudarya river basin).	+++ Flexible in structural modification and study area.	Available online to the public. Demo. 1999
TaiWAP	•Regional, Local. (Touchien river basin).	+	Available to National Taiwan University. Prototype. 2008
WADBOS	•Regional, Local. (Dutch Wadden sea).	+	Available online to the public. Demo. 2002

As far as the scale of application is concerned, all the examined DSS, except DIVA, have been applied only at the local and regional scales because they were developed for a specific geographical context. Moreover, five out of the 20 examined DSS (i.e. CLIME, CORAL, DITTY, DIVA and STREAM) considered global, supranational, national, regional and local scales during their implementation. Five of the reported DSS are highly flexible systems because they are used to address several impacts related to different case studies.

Although DIVA can be applied to any coastal area around the world, it is sometimes not considered a highly flexible tool in terms of structural modification due to its inability to change its default integrated dataset. Finally, ELBE and WADBOS are identified as moderately-to-no flexible systems because their structure and functionalities were based on the specific needs of particular river basins.

The applicability of DSS reflects their ability to be implemented in several contexts (i.e. case study areas and structural modification), for example to include new models and functionalities ensuring common approaches to decision making and the production of comparable results [42]. Finally, concerning the availability and the status of the development, Table 5 shows that nine DSS are available to the public, three are available with a restricted access (i.e. only to stakeholders or to the developers), one is a commercial software (i.e. COSMO) and seven are not available to the public.

Sometimes the restriction of the access is due to the fact that results require special skill for their interpretation, so the public can use them only with the support of the developer team. Among examined DSS, only 11 were developed/updated during the last 5 years, and 4 over the previous five years (for a total of 15 during the last 10 years) with the remaining five DSS showing the last version dating back to the '90s. The overall content of Table 5, together with the main features of each DSS reported in Tables 3 and 4, allow the reader to undertake a screening evaluation of available DSS in relation to the specific impacts from climate change to be addressed.

6. CLIMATE CHANGE & DSS FUNCTIONALITIES

Among the challenges of coastal environmental problems identified by [23, 8, 43 and 8] the paper elicits those related to climate change and categorises them into assessment and management aspects – bearing in mind that scientific solutions to climate change are often based on assessment and management procedures which are very contingent because assessment methodologies or approaches, data and tools could determine the robustness of potential management measures.

Thus, the examined DSS functionalities necessary to cope with climate change can be evaluated from an in depth consideration of framed questions intended to reflect the significant coastal systems challenges.

Assessment

- Does the DSS consider interdisciplinary processes/modelling?
- Does the DSS support spatial and temporal dimensions of coastal issues?
- Does the DSS consider uncertainty range or incomplete knowledge?
- Does the DSS support sensitivity analysis?
- Does the DSS predict potential effects of proposed scenarios?

Management

- Does the DSS consider the integration of science and policy / stakeholders involvement?
- Does the DSS support optimisation of management measures?
- Does the DSS make complex information understandable / aid visualization of processes?

An attempt to answer these questions, the paper synthesised the information elicited from the open literature survey in Table 3, 4 and 5. The results reflect the fact that, none of these tools possess all the functionalities related to both the assessment and management aspects.

However, they all appear to support the spatial and temporal dimensions of coastal processes; prediction of scenarios outcomes; integrated analysis of issues via in-inclusion of several models and approaches and making complex processes understandable through visualisation techniques e.g. GIS, 2D and 3D models etc. It should be noted, none of these DSS prove adequate sensitivity analysis of climate variables. Whereas only three (Coastal Simulator, CLIME and RegIS) partly consider uncertainty range via the application of the Monte Carlo Simulation and climate change projection analysis. RegIS adopts a novel 3D visualisation in order to communicate uncertainty associated with future coastal change modelling [33].

Nine out of the twenty DSS (COSMO, CVAT, DIVA, IWRM, KRIM, RegIS, SimLUCIA, SimCLIM and STREAM) partly support the optimisation of management measures, by considering effects related to different protection plans and, cost-benefit, socio-economic and mitigation options analysis. To a large extent stakeholders' participation is not fully supported by these tools even though there could be workshops and capacity building during development phases. Nonetheless potential users cannot use these tools effectively; for instance, four out of the twenty systems (ELBE, RegIS, KRIM and IWRM) support the provision of information for non-technical experts among which only RegIS can be used by stakeholders without the intervention of expert.

7. CONCLUSIONS

This work should be regarded as a preliminary attempt to describe and evaluate the main features of available DSS for the assessment and management of climate change impacts on coastal area and related inland watersheds. A further and comprehensive evaluation should be based on comparative application in selected and relevant case studies, in order to evaluate the DSS technical performance, especially in relation to datasets availability, that often represents the real limiting factor. Moreover, sensitivity and uncertainty analyses will provide further evidence of the reliability of the investigated DSS.

This review highlighted the relevance of developing climate change impact assessment and management at the regional scale (i.e. subnational and local scale), according to the requirements of policy and regulatory frameworks and to the methodological and technical features of the described DSS. In fact, most of the available DSS show a regional to local applicability with a moderate to high flexibility. Indeed climate change impacts are very dependent on regional geographical features, climate and socio-economic conditions and regionally-specific information can assist coastal communities in planning adaptation measures to the effects of climate change. Despite the current situation that shows available DSS mainly focusing on the analysis of specific individual climate change impacts and affected sectors (15 out of the 20 examined DSS), the further developments should aim at the adoption of ecosystem approaches considering the complex dynamics and interactions between coastal systems and other systems closely related to them (e.g. coastal aquifers, surface waters, river basins, estuaries).

The adoption of multi-risk approaches in order to consider the interaction among different climate change impacts that affect the considered region should also be a focus. Finally, it is important to remark the need to involve the end users and relevant stakeholders since the initial steps of the development process of these tools, in order to satisfy their actual requirements, especially in the perspective of providing useful climate services, and to avoid the quite often and frustrating situation where time and resource demanding DSS are not used beyond scientific testing exercises.

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